EMPIRICAL ANALYSIS ON RANDOM WALK BEHAVIOR OF FOREIGN EXCHANGE RATES

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EMPIRICAL ANALYSIS ON RANDOM WALK BEHAVIOR OF FOREIGN EXCHANGE RATES

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SUMMARY

This thesis conducts a comprehensive examination on the random walk behavior of 29 foreign exchange rates over the period of floating exchange regime, using variance-ratio tests. The cross-country and time-series test show that random walk model cannot be rejected on majority, and the random walk behavior is quite volatile across the whole floating exchange regime period. It then goes further to explore possible factors that can explain the probability of rejection/ non-rejections on random walk model using linear as well as nonlinear probability models, and find that the factors such as capital openness and investment-to-trade ratio significantly increases the chance of its exchange rate exhibiting random walk behavior.

CHAPTER I   INTRODUCTION

The foreign exchange market is currently the largest financial market in the world. Huge volume of transactions on foreign exchange take place in the international financial markets every day, among which, investment in foreign currency denominated assets is the main purpose for demand of foreign currencies, rather than conventional goods and service trade. Commercial and investment banks, multinational corporations, central banks are the major participants in foreign exchange market. However, the movements of foreign exchange rates are highly volatile. Therefore, lots of academic research has been attracted into the study of foreign exchange rate behavior.

Since 1960s, the theory of exchange rate determination has been developed to a profound extend. The development of Interest Rate Parity and Purchasing Power Parity, and several monetary models of exchange rate determination, and lots of sequential empirical analysis on these models played a large part in recent exchange rate research literatures. Among these studies, Frenkel (1976) finds strong evidence in support of the flexible-price monetary model for the German mark/US dollar exchange rate during 1920s, based on the uncovered interest parity condition. However, these monetary models cease to explain the variation in exchange rates beyond late 1970s. After examining both of the in-sample fit and out-of-sample forecast performance of various monetary models for the exchange rate data of seventies, Meese and Rogoff (1983) finds that these models cannot even beat the simple random walk model, which constructed a long-standing puzzle in exchange rate behavior. Frankel and Rose (1995) survey previous empirical literature on floating nominal exchange rates and concludes that, at short horizons, a driftless random walk characterizes exchange rates better than standard models based on observable macroeconomic fundamentals.

Starting the second half of 1990s, several studies then show that out-of-sample forecasting performance of monetary models improves upon a random walk model. MacDonald and Taylor (1994) demonstrated that an unrestricted monetary model is a valid framework for analyzing the long-run exchange rate, using a multivariate cointegration technique. They also find that, once proper account has been taken of the short-run data dynamics, that an unrestricted monetary model outperforms the random walk and other models. Mark (1995) and Chinn and Meese (1995) also find evidence that long-horizon changes in exchange rate is predictable from its fundamental variables. However, the results of these studies and their robustness have been called into question in subsequent researches by Kilian (1999), Berkowitz and Giorgianni (2001), and Faust, Rogers and Wright (2003). Cheung, Chinn and Pascual (2005) conducts a systematic out-of-sample testing on five major exchange rate determinant models, and compared their performance on different currencies along different time-horizons against the benchmark random walk model. The overall results showed that model/specification/currency combination that work well in one period do not necessarily work well in another period.

Lately, a growing number of studies have been reporting more positive short-term forecasting results by implementing panel forecast methods, innovative estimation procedures, more powerful out-of-sample test statistics, and new structural models. Kilian and Taylor (2003) develop a bootstrap test of the random walk hypothesis of exchange rates within the framework of nonlinear exponential smooth transition autoregressive model. The results provided strong evidence that predictability of the spot exchange rates improved dramatically as the forecast horizon is lengthened from one quarter to several years. Engel, Mark and West (2007) concluds that standard models based on macroeconomic variables imply near random walk behavior in exchange rates, so that their power to "beat the random walk" in out-of-sample forecasts is low. They also find evidence that, with panel techniques, monetary models generally produce better forecast than random walk. On the other hand, Rogoff and Stavrakeva (2008) challenge the findings from these recent studies. They argue that misinterpretation of some new out-of-sample tests of nested models, over-reliance on asymptotic test statistics, and failure to sufficiently check robustness to alternative time windows have led many studies to overstate even the relatively thin positive results that have been found.

Besides those mixed empirical results found by literature on exchange rates forecastability, a lot of effort was also dedicated into investigating the random walk behavior of exchange rates. However, the empirical evidences are not uniform either. For example, Baillie and Bollerslev (1989) find strong evidence of unit root in the univariate time-series representation for seven daily spot and forward exchange rate series. On the other hand, Lai and Pauly (1992) and Klaassen (2005) reject the random walk hypothesis. Belaire-Franch and Opong (2005) examine the behavior of some UK Financial Times Stock Exchange (FTSE) stock indices using rank and sign based variance-ratio tests suggested by Wright (2000) as well as conventional variance-ratio test. The results suggest that the random walk null of the index returns series is rejected. Further application of Wright's tests in a rolling window framework indicates that the results for FTSE returns are consistent neither with a linear AR assumption nor with the white noise hypothesis.

However, so far, no comprehensive test on the random walk behavior of foreign exchange rates during floating exchange regime has been conducted yet. Given the mixed evidence found by previous literature, this thesis tests the random walk hypothesis of exchange rate on a comprehensive data set including 29 foreign currencies during the floating exchange regime period since 1974, using both conventional Lo and MacKinlay (1988) variance-ratio tests and the Wright (2000) rank/sign-based variance-ratio tests.

In addition, each currency is tested using a 5-year rolling window in order to investigate how exchange rates behave differently across different time periods. This rolling regression approach gives us a way to look at the variation in the random walk behavior of exchange rates over time and across currencies.

After a comprehensive variance-ratio tests on 29 sample currencies during each 5-year sub-period, I find that it is hard to reject the random walk model of foreign exchange rates on majority. Pooling different currencies and different sub-periods together, only 20 percent of the exchange rate series can be rejected against the random walk null, even based on the results of rank/sign-based variance-ratio tests.

To further understands the random walk behavior of exchange rates and explore possible factors that can characterize the rejection and non-rejection probability of random walk models, the rejection binary variables of variance-ratio tests are regressed upon a few characteristic variables of exchange rates, using linear probability models and probit models. Empirical results suggest that, capital openness and investment-to-trade significantly increases the chance of its exchange rate exhibiting random walk behavior. This finding provides insights into possible factors that can explain the variation of random walk tendency overtime and across currencies.

The rest of this thesis is organized as follows: Chapter 2 describes the data set being investigated in this paper, Chapter 3 specifies the econometrics methodologies, including variance-ratio tests and regression models, Chapter 4 discusses empirical results, Chapter 5 concludes and gives some possible explanation for the major findings.

CHAPTER II DATA

The data set investigated in this paper is the weekly return of the foreign exchanges rates. Sample currencies investigated in this paper are focused only on those having two categories of exchange regime, managed or independently floating, as indentified according to the classification of exchange rate arrangements and monetary policy frameworks conducted by International Monetary Fund (IMF) on June 30, 2006. Excluding certain small economies that have negligible trade and investment flows, 29 countries are left including Euro Zone.

The sample period goes back to 1974, the year after the collapse of the Bretton Woods fixed exchange rate system, and ends until 2006. For each currency being investigated in this paper, its individual sample period starts at the time when the country switched to either management or independently floating exchange regime. For example, the sample period of India starts from March 1993 because that is when India has officially switched to managed floating exchange regime from an intermediate regime. There are four countries that have observations for the whole sample period from 1974 to 2006, which are Canada, Japan, Switzerland and United Kingdom.

The first three columns of the table in Appendix A list the country name, specific sample period, and numbers of observations for each sample foreign currency used in this paper.

The exchange rate is quoted as the Wednesday spot rate of foreign currency per unit of US Dollar (i.e. USD/Foreign Currency).[1] Weekly return of exchange rates is specified as the first order difference of the logarithm form of weekly exchange rates.

[1] Daily bilateral USD exchange rates for all currencies are obtained from Datastream.

For the purpose of this paper, other data are collected for the investigated currencies:

(1) *KAOPEN*, an index to measure a country's degree of capital account openness, proposed by Chinn and Ito (2002, 2005). This index is computed as the first principle component of the four binary variables reported in IMF's *Annual Report on Exchange Arrangements and Exchange Restrictions*: presence of multiple exchange rates, restrictions on current account transactions, restrictions on capital account transactions, and requirement of the surrender of export proceeds;

(2) $Investment - to - Trade\ Flow\ (ITF)\ ratio$, which measures the size of the capital flow relative to the trade flow between a foreign country and the U.S.. Capital flow is computed as the sum of total transactions in long-term domestic and foreign securities between the residents of a foreign country and the U.S. during a calendar year. [2] Trade flow refers to the sum of exports and imports between a foreign country and the U.S. during a calendar year.[3]

(3) *Independently floating regime dummy*, which equals to one if the currency is under independently floating exchange rate system according IMF and zero otherwise. However, the country is reclassified as not having independently floating exchange regime if the country has an IMF-supported or other monetary program as indicated in the notes of the IMF classification.[4]

(4) *Absolute percentage change in reserve*, which is designed to proxy for the central bank intervention activity. This variable is computed as the annual mean of monthly absolute percentage changes in reserve levels.[5]

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[2] Reported by the U.S. Treasury International Capital (TIC) Reporting System.
[3] Reported by the Foreign Trade Division of the U.S. Census Bureau.
[4] Column (6) of table in Appendix A gives the date of a switch from managed to independently floating regime if such a switch occurred.
[5] Monthly total reserve level data is obtained from International Financial Statistics dataset maintained by IMF.

Data for these explanatory variables are collected annually for the time period we need. Table 2.1 reports some summary statistics of these explanatory variables, while Table 2.2 reports the correlations between each pair of them:

Table 2.1 Summary Statistics of Explanatory Variables

Variable	Number of observations	Mean	Standard Deviation	Minimum Value	Maximum Value
KAOPEN	316	1.6578	1.3315	-1.7538	2.6233
ITF ratio	325	10.0899	22.2102	0	159.1728
Independently floating dummy	336	0.7470	0.4354	0	1
Absolute % change in Reserve	336	8.4619	7.5709	0.7337	54.6484

Table 2.2 Correlations between Explanatory Variables

	KAOPEN	ITF ratio	Independently floating dummy	Absolute % change in Reserve
KAOPEN	1.0000			
ITF ratio	0.2495	1.0000		
Independently floating dummy	0.2538	0.1719	1.0000	
Absolute % change in Reserve	-0.3022	-0.1184	0.1250	1.0000

As we can see from the above table, $KAOPEN$ and $ITF\ ratio$ are positively correlated since the size of investment flow is supposed to be higher in the market with higher degree of openness. *Independently floating regime dummy* is positively correlated with both of them as the investment activity is supposed to be higher under independently exchange regime than under managed exchange regime; while *Absolute percentage change in reserve* is negatively correlated with both of them as the central bank intervention is supposed to be less active in an more opened economy. However, all correlations between each pair are insignificant.

CHAPTER III ECONOMOTERICS METHODOLOGY

The main tool I adopt to test the random walk behavior of foreign exchange rates is variance-ratio (VR) tests. Sequentially, I use the linear probability model and probit model to explore the factors that can characterize the rejection or non-rejection of random walk by variance-ratio tests.

3.1 Variance Ratio Tests

In order to test whether the foreign exchange rates follows random walk, a comprehensive examination are conducted to the data set using both Lo-MacKinlay and Wight VR tests.

3.1.1 Lo-MacKinlay Tests

The conventional VR tests, developed by Lo and MacKinlay (1988), are commonly used to test the hypothesis that a series of time series data follows random walk model. Suppose y_t is a time series of asset returns, which is the weekly return of foreign exchange rates in this paper , with a sample size T. Define the variance-ratio as

$$VR = \frac{\frac{1}{Tk}\sum_{t=k+1}^{T}(y_t + y_{t-1} \dots + y_{t-k} - k\hat{\mu})^2}{\frac{1}{T}\sum_{t=1}^{T}(y_t - \hat{\mu})^2}$$

where $\hat{\mu} = \frac{1}{T}\sum_{t=1}^{T} y_t$, and k is factor of asset holding period, usually in the form of the statistic with overlapping data.

Under the random walk null, $\sqrt{T}(VR - 1)$ has asymptotic distribution $N\left(0, \frac{2(2k-1)(k-1)}{3k}\right)$. So the test statistic

$$M_1 = (VR - 1)\left(\frac{2(2k-1)(k-1)}{3kT}\right)^{-1/2}$$

is asymptotically standard normal under the null.

Furthermore, if y_t exhibits conditional heteroscedasicity, the robustified test statistic

$$M_2 = (VR - 1)(\sum_{j=1}^{k-1} \left[\frac{2(k-j)}{k}\right]^2 \delta_j)^{-1/2},$$

where $\delta_j = \frac{\sum_{t=j+1}^{T}(y_t - \hat{\mu})^2 (y_{t-j} - \hat{\mu})^2}{\left[\sum_{t=1}^{T}(y_t - \hat{\mu})^2\right]^2}$, is also asymptotically standard normal under the null.

3.1.2 Wright Tests

Based on the Lo-MacKinlay tests, J. Wright (2000) proposed two alternative VR tests using ranks and signs.

Let $r(y_t)$ be the rank of y_t among the time series $\{y_1, y_2, \dots, y_T\}$. Define

$$r_{1t} = \left(r(y_t) - \frac{T+1}{2}\right) / \sqrt{\frac{(T-1)(T+1)}{12}}$$

$$r_{2t} = \Phi^{-1}\left(\frac{r(y_t)}{T+1}\right),$$

where Φ is the standard normal cumulative distribution. The series $\{r_{1t}\}$ is simply a linear transformation of the ranks, with sample mean 0 and sample variance 1. The series $\{r_{2t}\}$ has sample mean 0 and sample variance approximately equal to 1.

Substituting r_{1t} and r_{2t} in the place of y_t in the definitions of M_1 and M_2 statistics respectively, the **rank-based variance-ratio test statistics** are defined as

$$R_1 = \left(\frac{\frac{1}{Tk}\sum_{t=k+1}^{T}(r_{1t} + r_{1t-1} \dots + r_{1t-k})^2}{\frac{1}{T}\sum_{t=1}^{T} r_{1t}^2} - 1\right)\left(\frac{2(2k-1)(k-1)}{3kT}\right)^{-1/2}$$

$$R_2 = \left(\frac{\frac{1}{Tk}\sum_{t=k+1}^{T}(r_{2t} + r_{2t-1} \dots + r_{2t-k})^2}{\frac{1}{T}\sum_{t=1}^{T} r_{2t}^2} - 1\right)\left(\frac{2(2k-1)(k-1)}{3kT}\right)^{-1/2}.$$

Let $s_t = 2u(y_t, 0)$, where function $u(x_t, q) = 1(x_t > q) - 0.5$, the signed-based variance-ratio statistic using s_t is defined as

$$S_1 = \left(\frac{\frac{1}{Tk}\sum_{t=k+1}^{T}(s_t + s_{t-1} \ldots + s_{t-k})^2}{\frac{1}{T}\sum_{t=1}^{T} s_t^2} - 1 \right) \left(\frac{2(2k-1)(k-1)}{3kT} \right)^{-1/2}.$$

Under the null that y_t is independently and identically distributed (iid), R_1, R_2 and S_1 will have exact distribution. While if there exists heteroscedasicity, their distribution are not exact. However, Wright shows that the exact sampling distribution of R_1, R_2 and S_1 can be simulated to an arbitrary degree of accuracy for different choices of T and k. He also presents that the sampling distribution have very small distribution in the presence of heteroscedasicity via Mote Carlo simulations.

Basing on the Monte Carlo experiments Wright performed in his paper, evidence showed that rank-based tests R_1 and R_2 are nearly always more powerful than the conventional Lo and MacKinlay variance-ratio tests (M_1 and M_2). The signed-based test S_1 has generally less power than the rank-based tests, but can be more powerful than the conventional VR tests.

3.1.3 Five-year Rolling Window

Within the framework of comprehensive VR tests across the whole 29-country sample, for every sample country with more than 200 observation of weekly exchange rates, the VR tests are conducted using 5-year rolling window. Assuming each year has 52 weeks on average, the first 5-year sub-period starts from y_1 to y_{260} (260=52*5). Then I move the rolling window one year (52 observations) forward, which makes the second 5-year sub-period from y_{53} to y_{312}. The procedure moves on every time with 52 observations forward, until the end of the specific sample period of this currency.

i.e. for series $\{y_t\}$ with a sample size T $(\mathrm{T} > 200)$,

Period 1: $y_1, \; y_2, \ldots, y_{260}$

Period 2: y_{53}, y_{54}, … , y_{312}

…

Period j: $y_{52(j-1)+1}$, $y_{52(j-1)+2}$, ⋯ , $y_{\min\{52(j+4),T\}}$

For example, for British pound, the sample period starts from the beginning of 1974 to the end of 2006. So a total of 29 rolling windows can be proceeded. Except the case that the last time period is not long enough for 5 years, every 5-year window contains exact 260 observations. Column (4) and (5) of the table in Appendix A give the number of rolling windows and the middle-years of these windows for each sample currency.

For every 5-year sub-period of each sample currency, all five types of VR tests (M_1, M_2, R_1, R_2 and S_1) are conducted for holding period $k = 8$. The null hypothesis is rejected if the statistic value falls into the two-tailed 5% rejection area. That is, if M_1 or M_2 value is less than the 2.5% critic value or larger than the 97.5% critic value of standard normal distribution, we reject the null hypothesis that the exchange rate series follows random walk. Same rejection criteria is taken for R_1, R_2 and S_1 tests. Table 3.1 gives critic values of the distributions of for $\mathrm{T} = 260$, $k = 8$.

Table 3.1 Critic Values of Distribution of R_1, R_2 and S_1

$T = 260$, $k = 8$

	0.5%	2.5%	5%	95%	97.5%	99.5%
R_1	-2.43282	-1.98947	-1.75169	1.409398	1.809439	2.568591
R_2	-2.43258	-1.98692	-1.75226	1.383397	1.772835	2.645547
S_1	-2.30623	-1.85546	-1.61436	1.572427	1.94981	2.78849

Note: These critic values were simulated with 10,000 replications in each cases. Each statistics are compared with the 2.5% and 97.5% critic values as we reject the null in a two-tailed 5% rejection area.

Afterwards, a rejection binary variable $D(W), W = M_1, M_2, R_1, R_2, S_1,$ is generated for each type of VR test, which equals 1 if we reject the random walk null under this particular test, and 0 otherwise.

i.e. $D(W) = \begin{cases} 1, & if\ reject\ null\ under\ test\ W \\ 0, & otherwise \end{cases}$.

3.2 Econometrics Models

The next question after testing the random walk behavior of foreign exchange rates is to investigate what kind of factors affect the random walk behaviors exhibited by different currencies during different time periods. In order to explore the possible explanatory factors, I conduct the regression analysis on the probabilities of random walk rejection, which are indicated by five types of rejection binary variables ($D(W), W = M_1$, M_2, R_1, R_2, S_1) generated by the VR tests above, upon certain characteristic variables of different exchange rates within the framework of linear probability model (LPM) and probit model.

3.2.1 Linear Probability Model (LPM)

The regression equation of LPM is specified as following,

$y = \boldsymbol{X\beta} + u$, where $\boldsymbol{X}$ is the vector of independent variables.

When y is a binary variable taking on values zero and ones, the probability that $y = 1$ is the same as the expected value of y. i.e.

$$\mathrm{P}(y = 1|\boldsymbol{X}) = \mathrm{E}(y|\boldsymbol{X}) = \boldsymbol{X\beta}$$

Thus, the coefficient of a certain explanatory variable measures the change in the probability of $y = 1$ when that variable changes. In this way, the regression model allows us to estimate the effect of explanatory variables on qualitative events. The coefficients are estimated using ordinary least squares (OLS), while standard errors are corrected for heteroskedasticity.

3.2.2 Probit Model

The regression equation of probit model is the following,

$y = \Phi(\boldsymbol{X\beta}) + u$, where $\Phi(z)$ is the standard normal cumulative density function, and $\boldsymbol{X}$ is the vector of independent variables.

In this case, $\mathrm{P}(y = 1|\boldsymbol{X}) = \Phi(\boldsymbol{X\beta})$. The partial effect of a roughly continuous variable, x_j, on the probability of $y = 1$ is given by $g(X\beta)\beta_j$, where $g(z) = \frac{\mathrm{d}\Phi}{\mathrm{d}z}(z)$ i.e. the probability density function of standard normal distribution. Since $\Phi(z)$ is a strictly increasing density function, which means that the partial effect of x_j always has the same sign as β_j. The coefficients of probit models are estimated by maximum likelihood estimation (MLE).

Comparing two models, LPM assumes that the response probability is a linear set of parameters, while probit model avoids this limitation by using the nonlinear density function $\Phi(z)$. Thus the cross-model check allows to examine the effects of explanatory variables on exchange rate random walk behavior within both linear and nonlinear framework.

I use a set of factors that can characterize the random walk behavior of foreign currencies. One key variable is to use a measure that can capture how frequently a currency is used for investment purposes relative to trade in goods and services. However, there is no perfect measurement for the investment intensity of a certain currency. In this paper, I adopt the following two commonly used proxies,

(1) *KAOPEN*, an index to measure a country's degree of capital account openness, proposed by Chinn and Ito (2002, 2005). Although financial openness is not the only determinant of investment, an open capital market is essential for the presence of substantial investment flow. This index is aimed to measure the intensity of capital

controls. It ranges from negative to positive, and has a higher value if a higher degree of capital openness.

(2) $Investment - to - Trade\ Flow\ (ITF)\ ratio = \frac{Capital\ \ flow}{Trade\ \ flow} * 100$, which measures the size of the capital flow between a foreign country and the U.S. relative to that of the trade flow.

Intuitively speaking, as the intensity for investment usage of a currency increases, the chance it might exhibit random walk behavior increases. Therefore, both *KAOPEN* and $ITF\ ratio$ are expected to have negative effect on the probability of rejecting random walk models for exchange rates.

Two other variables are used to control for the cross-sectional variation in the characteristics of currencies:

(1) *Independently floating regime dummy*, which equals to one if the currency is under independently floating exchange rate system and zero otherwise. This dummy variable is expected to negatively affect the rejection probability of random walk models as the exchange rate of currency is supposed to suffer less interventions under independently floating regime than under managed floating regime.

(2) *Absolute percentage change in reserve*, which is designed to proxy for the central bank intervention activity. The adoption of this variable is to further control the possible impact of central bank intervention on the behavior of exchange rates, since central bank intervention usually plays an important role on affecting exchange rate behavior. We expect to see positive effect of central bank intervention on the rejection probability of random walk models.

For all of the explanatory variables, the mid-year values of each 5-year period are used in the LMP and probit regressions for corresponding periods.

CHAPTER IV EMPIRICAL RESULTS

4.1 Radom Walk Behavior

I first compute the VR tests for the entire sample period for each sample currency. Table 4.1 reports the results for the five types of VR tests. The last row summarizes total number of rejecting the random walk null for each type of test. As we can see, Wright's rank-based and sing-based VR tests tend to reject the random walk null stronger than the conventional Lo-MacKinlay VR tests, which is consistent with the Monte Carlo evidence found by Wright that the VR tests using ranks and signs have stronger power than the conventional VR tests. According to the Wright test results, more than half of the sample currencies do not follow random walk model within their entire sample periods.

Table 4.1 VR Test Result for Entire Sample Period (k=8)

Country	Number of Observations	M_1	M_2	R_1	R_2	S_1
Argentina	259	0.51833	0.17881	0.60878	0.24132	0.57879
Australia	1203	0.36787	0.27665	0.78093	0.20445	0.72157
Brazil	413	-1.06461	-0.53593	2.62702*	1.60615	3.33102*
Canada	1722	0.34014	0.27115	2.00517*	1.08104	3.26368*
Chile	518	2.85341*	2.81650*	3.79818*	3.37732*	2.70114*
Colombia	379	2.26094*	1.57077	3.49140*	2.82560*	3.92100*
Czech	501	0.38258	0.36671	0.86810	0.47182	2.30558*
European Union	417	0.69697	0.65892	1.44611	0.77104	1.36742
Germany	1261	1.99149*	1.71368	3.49390*	2.70744*	2.77619*
India	722	2.19195 *	0.97042	4.65381*	4.18460*	5.44521*
Indonesia	926	0.09152	0.01964	2.89835*	2.93695*	3.41799*
Japan	1722	4.27089*	3.65777*	5.41424*	4.64497*	4.79570*
Korea	472	-1.92790	-0.85518	0.48699	0.76421	0.04673
Malaysia	283	-0.29823	-0.14622	-0.20247	-0.16269	-0.82538
Mexico	627	-0.93227	-0.45402	-0.61519	-0.93564	0.33104
New Zealand	1139	0.40852	0.35065	0.88740	0.74671	1.09232

Norway	850	-0.07658	-0.06890	1.03149	0.32247	0.91347
Peru	813	3.88263*	1.50890	3.82422*	3.97213*	1.57786
Philippines	1160	0.11776	0.05391	6.31255*	5.22616*	9.11088*
Poland	351	-0.74431	-0.67963	0.10398	-0.60575	0.69570
Russia	434	-6.00892*	-1.12617	4.13557*	2.91193*	3.25736*
Singapore	1148	1.91801	1.19828	2.65081*	2.37090*	3.03450*
South Africa	617	1.66558	1.20347	2.11979*	2.00290*	1.19183
Sweden	815	1.52705	1.35473	1.98618*	1.55798	1.20268
Switzerland	1722	1.95527	1.65470	3.02224*	2.36767*	2.58324*
Thailand	505	3.03874*	1.20312	2.84273*	2.74913*	0.94207
Turkey	305	0.78558	0.52467	2.27696*	1.90038*	2.27823*
UK	1722	2.34957*	1.78583	3.21249*	2.57807*	2.23691*
Uruguay	237	-0.17635	-0.06701	0.65856	0.07795	2.64071*
Total Rejection		**9**	**2**	**18**	**15**	**16**

Note: * mark indicates rejection of the random walk null at two-tailed 5% significance level. M1 and M2 values are compared with the critic values of standard normal distribution. R1, R2 and S1 values are compared with the critic values of the exact distributions for the according sample size simulated with 10,000 replications in each case.

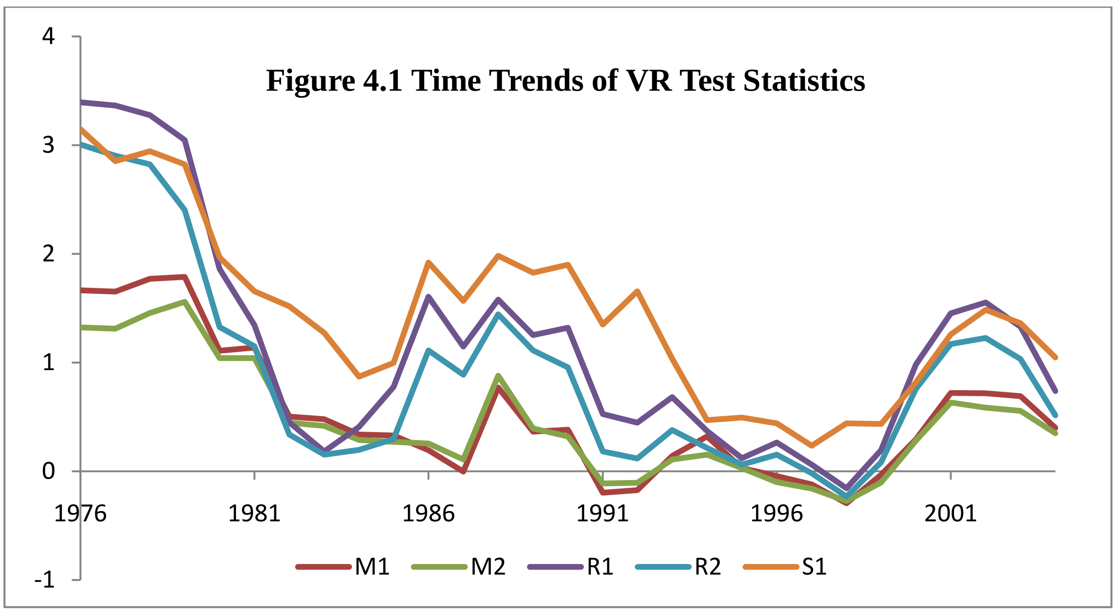
Sequentially I conduct the variance tests across the 29 sample countries with 5-year rolling window, as described in Chapter 3.1. A total number of 336 values is obtained for each type of VR test statistics when different currencies and different sub-periods are pooled together. Table 4.1 reports some descriptive statistics of the 5 rejection binary variables generated by the VR tests.

Table 4.2 Summary Statistics of Rejection Binaries by VR Tests

	Number of Obs.	Std. Dev.	Percent of D(W)=1
$\boldsymbol{D(M_1)}$	336	.3346	12.80%
$\boldsymbol{D(M_2)}$	336	.2676	7.74%
$\boldsymbol{D(R_1)}$	336	.4170	22.32%
$\boldsymbol{D(R_2)}$	336	.3956	19.35%
$\boldsymbol{D(S_1)}$	336	.4046	20.54

The percentage of taking value 1 for $D(R_1), D(R_2)$ and $D(S_1)$ is around 20%, which is significantly larger than this percentage value of $D(M_1)$ or $D(M_2)$. However, the 20% probability of rejection suggest only one-fifth of the total 336 exchange rate series can rejected against the random walk null hypothesis, which is hard to convince us the non-random walk behavior of foreign exchange rates.

Furthermore, for each 5-year sub-period, I compute the average mean of five VR test statistics across the countries that have observations covering that sub-period. Since four currencies have observations for the whole sample period from 1974 to 2006, there are at least four values of each VR statistic for computing country-cross average at each sub-period. But the numbers vary over different sub-periods, as each currency has specific sample periods. Figure 4.1 gives the time trends of five VR statistics.



Note: The country-cross average value is computed for each statistic at each 5-year sub-period. The time axis labels the middle-year of each sub-period.

As we can see from the graph, although the values of five VR statistics are not directly comparable with each other, the country-cross average of five statistics do move together across the sample period. The group of Lo-MacKinlay test statistics (M_1 and M_2) tends to behave similarly, while the behavior of Wright test statistics, especially M_1 and

M_2, have similar pattern with each other. In addition, the Wright test statistics show more variation than the Lo-MacKinlay statistics, which can also be told by the standard deviations in Table 4.1

However, the time trends exhibit huge volatility because of the different characters among the currencies entering and leaving each sub-period. Since VR statistics should have a mean value of zero under the random walk null, the time plots also suggest that on average sample currencies were far from random walk during 1970s and also exhibited some degree of random walk behavior during the late 1980s. Then they tend to behave on average closer to random walk during early 1990s with some deviation from random walk in late 1990s. These observations may be useful as they provide evidence of variation in random walk behavior over time.

To further understand the time trend behavior of VR statistics, I regress each of the five VR statistics individually on a constant and a time variable. The regression result is reported in Table 4.2. The estimated coefficient on time trend variable is negative and statistically significant at 5% level across all five regressions, which suggests that, on average, VR statistics decrease over time as countries become more open and globalization tends to increase capital movements and the investment related to purchase and sale of currencies.

Table 4.3 Time Trend Analysis of VR Test Statistics

	M_1	M_2	R_1	R_2	S_1
Intercept	1.1723	1.0236	2.1923	1.7961	2.4402
	(.000)	(.000)	(.000)	(.000)	(.000)
Time Trend	-.0439	-.0385	-0.0691	-.0606	-.0667
	(.002)	(.001)	(.005)	(.006)	(.000)
R-squared	.3787	.4034	.3339	.3239	.5035

Note: Numbers in parenthesis are p-values of t-test using heteroskefasticity-robust standard errors.

4.2 Regression Results

The empirical results of regression models described in Chapter 3.2 are reported in Appendix B. Table B.1-B.5 report the results of LPM. Table B.6-B.10 contain the results of probit models. In each table, every column represents a regression specification with one possible combination of explanatory variables.

Although the magnitude of the coefficient estimates between LPM and probit models are not directly comparable, the estimates across both models for all 5 rejection binary variables of random walk hypothesis tell a consistent story. Both coefficients on *KAOPEN* and *ITF ratio* are negative and statistically significant at 5% level across all eight regression specifications for both models, which is consistent as we expected in Chapter 3.2. It suggests that both the degree of financial openness and the investment-to-trade flow ratio significantly decrease the probability of rejecting random walk behavior on a currency's exchange rate, whether we assume linear or nonlinear models. This evidence implies that, with a higher degree of country's financial openness or a higher ratio of it capital flow relative to trade flow, the chance of its exchange rate exhibits random walk increases. This result is also robust when we add the *Independently floating regime dummy* and the *Absolute percentage change in reserve* variable for control. However, the effects tend to be lower when these control variables are added.

The coefficients on *Independently floating regime dummy* and the *Absolute percentage change in reserve* variables also exhibit expected signs (negative and positive perspective). It suggests that the exchange rate of currency tends to exhibit more close to random walk if it is under independently floating regime than under managed floating regime. While the chance of random walk decreases with a higher degree of central bank intervention. But their effects on the random walk behaviors of exchange rates do not keep consistently significant across models.

CHAPTER V CONCLUSION

This paper is mainly focused on investigating the random walk behavior of foreign exchange rates over the floating exchange regime period. A comprehensive examination on the weekly returns of exchange rates using variance-ratio tests with a five-year rolling window is conducted over 29 sample currencies. Further exploration on possible explanatory factors affecting the probability of random walk behavior is also discussed within the framework of linear and nonlinear probability models.

The empirical evidences give the following major implications:

(1) It is hard to reject the random walk model hypothesis of foreign exchange rates on majority when we examine them both cross country and cross sub-periods. And the random walk behavior of exchange rates is highly volatile across the floating exchange regime period. On average, they tend to move more close to random walk over time as counties become more financially open and degree of globalization increases.

(2) The probability of a currency's exchange rate exhibits random walk behavior increases if the country has a higher degree of financial openness or a higher investment-to-trade flow ratio.

This paper extends the existing research literature on the random walk behavior of foreign exchange rates, by conducting a comprehensive variance-ratio examination both cross country and cross sub-periods for the first time. The finding on the significant effects of financial openness and investment flow on the random walk probability of exchange rates would also contributes to the current understanding on exchange rate behaviors, as it gives useful implication on the implement of monetary policies.

However, the implication of results is still limited. The probability models are estimated with pooling the country/time-cross data together. Possible improvement can be made if we can examine the random walk behavior within a framework of panel data, so that we can control the fixed effects and random effects to find more solid empirical evidences.

APPENDIX A: SAMPLE CURRENCIES

(1) Country	(2) Sample Period	(3) Number of Observations	(4) Number of Rolling Windows	(5) Mid-years of Rolling Windows	(6) Change in Regime
Argentina	01/16/2002-12/27/2006	259	1	2004	
Australia	12/24/1983-12/27/2006	1203	20	1985-2004	
Brazil	02/03/1999-12/27/2006	413	4	2001-2004	
Canada	01/02/1974-12/27/2006	1722	29	1976-2004	
Chile	01/29/1997-12/27/2006	518	6	1999-2004	09/02/1999
Colombia	09/29/1999-12/27/2006	379	3	2001-2003	
Czech	05/28/1997-12/27/2006	501	5	1999-2003	
European Union	01/06/1999-12/27/2006	417	4	2001-2004	
Germany	01/02/1974-12/30/1998	1261	20	1976-1995	
India	03/03/1993-12/27/2006	722	10	1995-2004	
Indonesia	04/05/1989-12/27/2006	926	14	1991-2004	08/14/1997
Japan	01/02/1974-12/27/2006	1722	29	1976-2004	
Korea	12/17/1997-12/27/2006	472	6	1999-2004	
Malaysia	04/07/1993-09/02/1998	283	1	1995	
Mexico	12/28/1994-12/27/2006	627	9	1996-2004	
New Zealand	03/06/1985-12/27/2006	1139	18	1987-2004	
Norway	10/24/1990-12/27/2006	850	13	1992-2004	12/10/1992
Peru	06/05/1991-12/27/2006	813	12	1993-2004	
Philippines	10/10/1984-12/27/2006	1160	19	1986-2004	
Poland	04/12/2000-12/27/2006	351	3	2002-2004	
Russia	09/09/1998-12/27/2006	434	5	2000-2004	
Singapore	01/02/1985-12/27/2006	1148	18	1987-2004	
South Africa	03/08/1995-12/27/2006	617	8	1997-2004	
Sweden	05/22/1991-12/27/2006	815	12	1993-2004	11/19/1992
Switzerland	01/02/1974-12/27/2006	1722	29	1976-2004	
Thailand	07/02/1997-12/27/2006	505	6	1999-2004	
Turkey	02/28/2001-12/27/2006	305	2	2003-2004	
UK	01/02/1974-12/27/2006	1722	29	1976-2004	
Uruguay	06/19/2002-12/27/2006	237	1	2004	

APPENDIX B: REGRESSION RESULTS OF ECONOMETRIC MODELS

The following tables present the estimated coefficients of LPM and probit model regressions on the probability of rejecting random walk in exchange rate. Response binary variable ($D(W), W = M_1, M_2, R_1, R_2, S_1$) equals one if random walk is rejected at five percent level based on the according variance-ratio test computed with k=8 over five-year periods, and zero otherwise. *KAOPEN* index is a measure of financial openness developed and updated by Chinn and Ito (2002, 2005). *ITF ratio* measures the size of the capital flow between a foreign country and the U.S. relative to that of the trade flow. *Independently floating regime dummy* equals to one if the currency is under independently floating exchange rate system according IMF and zero otherwise. *Absolute percentage change in reserve* is designed to proxy for the central bank intervention activity, and it is computed as the annual mean of monthly absolute percentage changes in reserve levels.

Table B.1-B.5: Regression Results of LPM

Note: For each independent variable, the estimated coefficients by each LPM regression are list in the first row of the corresponding variable. Models are estimated using OLS. The corresponding p-values of t-test based on heteroskedasiticity-robust standard errors are provided in parentheses.

Table B.1 Result of LPM for $D(M_1)$

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Intercept	.2660	.1529	.2824	.0786	.3526	.3104	.2879	.2376
	(.000)	(.000)	(.000)	(.010)	(.000)	(.000)	(.000)	(.000)
KAOPEN	-.0784				-.0653	-.0557		
	(.000)				(.000)	(.002)		
ITF ratio		-.0020					-.0014	-.0010
		(.016)					(.000)	(.003)
Independently floating dummy			-.2067		-.1482	-.1664	-.1914	-.2112
			(.000)		(.005)	(.002)	(.000)	(.000)
Absolute % change in Reserve				.0058		.0047		.0073
				(.069)		(.137)		(.019)
N	316	325	336	336	316	316	325	325
R-square	.0924	.0179	.0723	.0175	.1265	.1363	.0778	.1038

Table B.2 Result of LPM for $D(M_2)$

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Intercept	.1755 (.000)	.0937 (.000)	.1412 (.000)	.0663 (.011)	.1980 (.000)	.2067 (.000)	.1456 (.000)	.1343 (.000)
KAOPEN	-.0562 (.000)				-.0528 (.001)	-.0548 (.001)		
ITF ratio		-.0014 (.036)					-.0011 (.000)	-.0010 (.001)
Independently floating dummy			-.0854 (.036)		-.0386 (.356)	-.0348 (.339)	-.0736 (.076)	-.0780 (.058)
Absolute % change in Reserve				.0013 (.622)		-.0010 (.731)		.0016 (.548)
N	316	325	336	336	316	316	325	325
R-square	.0740	.0123	.0193	.0014	.0776	.0783	.0261	.0281

Table B.3 Result of LPM for $D(R_1)$

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Intercept	.4374 (.000)	.2645 (.000)	.4235 (.000)	.1571 (.000)	.5442 (.000)	.5138 (.000)	.4336 (.000)	.3685 (.000)
KAOPEN	-.1283 (.000)				-.1121 (.000)	-.1052 (.000)		
ITF ratio		-.0033 (.000)					-.0026 (.000)	-.0020 (.000)
Independently floating dummy			-.2682 (.000)		-.1828 (.001)	-.1959 (.001)	-.2397 (.000)	-.2654 (.000)
Absolute % change in Reserve				.0078 (.020)		.0034 (.250)		.0094 (.003)
N	316	325	336	336	316	316	325	325
R-square	.1670	.0310	.0784	.0201	.2021	.2056	.0918	.1199

Table B.4 Results of LPM for $D(R_2)$

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Intercept	.4007 (.000)	.2316 (.000)	.4000 (.000)	.1285 (.000)	.5125 (.000)	.4701 (.000)	.4091 (.000)	.3439 (.000)
KAOPEN	-.1214 (.000)				-.1045 (.000)	-.0948 (.000)		
ITF ratio		-.0031 (.000)					-.0023 (.000)	-.0018 (.000)
Independently floating dummy			-.2765 (.000)		-.1914 (.001)	-.2096 (.000)	-.2516 (.000)	-.2773 (.000)
Absolute % change in Reserve				.0077 (.021)		.0048 (.104)		.0094 (.003)
N	316	325	336	336	316	316	325	325
R-square	.1632	.0302	.0926	.0216	.2052	.2125	.1045	.1357

Table B.5 Results of LPM for $D(S_1)$

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Intercept	.4362 (.000)	.2459 (.000)	.3882 (.000)	.1418 (.000)	.5201 (.000)	.4921 (.000)	.3985 (.000)	.3371 (.000)
KAOPEN	-.1352 (.000)				-.1225 (.000)	-.1161 (.000)		
ITF ratio		-.0033 (.000)					-.0026 (.000)	-.0022 (.030)
Independently floating dummy			-.2448 (.000)		-.1436 (.007)	-.1557 (.003)	-.2164 (.000)	-.2406 (.000)
Absolute % change in Reserve				.0075 (.026)		.0032 (.279)		.0089 (.006)
N	316	325	336	336	316	316	325	325
R-square	.1935	.0326	.0694	.0198	.2160	.2191	.0852	.1117

Table B.6-B.10: Regression Results of Probit Models

Note: For each independent variable, the coefficients by each probit model regression are list in the first row of the corresponding variable. Models are estimated using MLE. The corresponding p-values of standard normal test are provided in parentheses. The pseudo R-squared is the measure based on log-likelihood.

Table B.6 Results of Probit Model for $D(M_1)$

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Intercept	-.6641	-.7239	-.5859	-1.335	-.3172	-.4779	-.2532	-.4578
	(.000)	(.000)	(.000)	(.000)	(.046)	(.012)	(.151)	(.020)
KAOPEN	-.3256				-.2814	-.2418		
	(.000)				(.000)	(.001)		
ITF ratio		-.0942					-.0948	-.0881
		(.001)					(.002)	(.006)
Independently floating dummy			-.8588		-.6401	-.7286	-.7576	-.8673
			(.000)		(.001)	(.000)	(.000)	(.000)
Absolute % change in Reserve				.0218		.0182		.0265
				(.031)		(.117)		(.015)
N	316	325	336	336	316	316	325	325
Pseudo	.1052	.0831	.0828	.0179	.1465	.1563	.1436	.1669

Table B.7 Results of Probit Model for $D(M_2)$

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Intercept	-.9870 (.000)	-.9055 (.000)	-1.075 (.000)	-1.488 (.000)	-.8380 (.046)	-.7915 (.000)	-.6155 (.004)	-.6542 (.005)
KAOPEN	-.3311 (.000)				-.3118 (.000)	-.3249 (.000)		
ITF ratio		-.1521 (.002)					-.1582 (.002)	-.1564 (.002)
Independently floating dummy			-.5162 (.015)		-.2643 (.251)	-.2362 (.323)	-.4377 (.054)	-.4614 (.049)
Absolute % change in Reserve				.0074 (.531)		-.0056 (.66)		.0053 (.665)
N	316	325	336	336	316	316	325	325
Pseudo	.1162	.1168	.1168	.0021	.1234	.1245	.1371	.1381

Table B.8 Results of Probit Model for $D(R_1)$

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Intercept	-.1832 (.111)	-.4163 (.000)	-.1929 (.159)	-.9622 (.000)	.1697 (.279)	.0812 (.658)	.0160 (.915)	-.1858 (.271)
KAOPEN	-.4039 (.000)				-.3605 (.000)	-.3392 (.000)		
ITF ratio		-.0628 (.000)					-.0570 (.001)	-.0510 (.003)
Independently floating dummy			-.8208 (.000)		-.6138 (.001)	-.6595 (.000)	-.6816 (.000)	-.7788 (.000)
Absolute % change in Reserve				.0227 (.017)		.0105 (.354)		.0268 (.009)
N	316	325	336	336	316	316	325	325
Pseudo	.1453	.0740	.0676	.0163	.1785	.1811	.1187	.1388

Table B.9 Results of Probit Model for $D(R_2)$

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Intercept	-.2876 (.013)	-.3654 (.002)	-.2533 (.065)	-1.074 (.000)	-.1002 (.522)	-.0381 (.835)	.1462 (.382)	-.0678 (.715)
KAOPEN	-.4023 (.000)				-.3569 (.000)	-.3236 (.000)		
ITF ratio		-.1140 (.000)					-.1151 (.000)	-.1080 (.000)
Independently floating dummy			-.9043 (.000)		-.6871 (.000)	-.7646 (.000)	-.7928 (.000)	-.8978 (.000)
Absolute % change in Reserve				.0234 (.015)		.0165 (.153)		.0278 (.008)
N	316	325	336	336	316	316	325	325
Pseudo	.1488	.1115	.0848	.0183	.1918	.1984	.1718	.1940

Table B.10 Results of Probit Model for $D(S_1)$

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Intercept	-.1918 (.096)	-.3059 (.009)	-.2839 (.040)	-1.022 (.000)	.0958 (.547)	.0176 (.924)	.1268 (.444)	-.0606 (.742)
KAOPEN	-.4413 (.000)				-.4034 (.000)	-.3841 (.000)		
ITF ratio		-.1179 (.000)					-.1187 (.000)	-.1129 (.000)
Independently floating dummy			-.7811 (.000)		-.4990 (.008)	-.5420 (.005)	-.6605 (.000)	-.7472 (.000)
Absolute % change in Reserve				.0225 (.019)		.0094 (.409)		.0244 (.018)
N	316	325	336	336	316	316	325	325
Pseudo	.1731	.1169	.0623	.0165	.1944	.1965	.1582	.1754

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